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Massachusetts Institute of Technology
Department of Economics
Working Paper Series

# INFLATION TARGETING AND SUDDEN STOPS

Ricardo J. Caballero
Arvind Krishnamurthy

Working Paper 03-10
February 19, 2003

Room E52-251
50 Memorial Drive
Cambridge, MA 02142

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# Inflation Targeting and Sudden Stops

Ricardo J. Caballero  Arvind Krishnamurthy*

This draft: February 19, 2003

**Abstract**

Emerging economies experience sudden stops in capital inflows. As we have argued in Caballero and Krishnamurthy (2002), having access to monetary policy during these sudden stops is useful, but mostly for "insurance" rather than for aggregate demand reasons. In this environment, a central bank that cannot commit to monetary policy choices will ignore the insurance aspect and follow a procyclical rather than the optimal countercyclical monetary policy. The central bank will also intervene excessively to support the exchange rate. These inefficiencies are exacerbated by the presence of an expansionary bias. In order to solve these problems, we propose modifying the central bank's objective to (i) include state-contingent inflation targets, (ii) target a measure of inflation that overweights non-tradable inflation, and (iii) weigh reserves holdings.

**JEL Codes:** E0, E4, E5, F0, F3, F4, G1

**Keywords:** External shocks, domestic and international liquidity, inflation targeting, fear of floating, commitment, underinsurance.

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*Respectively: MIT and NBER; Northwestern University. This paper was prepared for the NBER's Conference on Inflation Targeting, January 23-26, 2003, Bal Harbour, Florida. We are grateful to Ben Bernanke, Andrew Hertzberg and conference participants for their comments. We thank Donna Zerwitz for editorial assistance. Caballero thanks the NSF for financial support. Krishnamurthy thanks the IMF for their hospitality while this paper was being written. All errors are our own. E-mails: caball@mit.edu, a-krishnamurthy@northwestern.edu.

# 1 Introduction

Underlying weaknesses in the domestic financial sector and limited integration with world financial markets make emerging market economies vulnerable to "sudden stops" of capital inflows. Without much warning, the capital flows that support a boom may come to a halt, exposing the country to an external crisis.

Monetary policy in this context has often been seen as an additional source of problems rather than as a remedy. Countries with a history of inflation problems have limited central bank credibility. The currency pressures of the sudden stop test this credibility, so that either the loss of credibility or the attempt to regain it in the middle of the crisis exacerbates the contraction.

However, there is a group of countries for which the problem of high and unstable inflation is no longer present but the problem of sudden stops persists. These countries include Chile, Mexico, and many of the Asian economies. Moreover, looking towards the future, this group is bound to grow, as hopefully Brazil, Turkey, and countries of Eastern Europe establish discipline over seignorage and fiscal policies.

Many of these advanced emerging economies are now in the process of designing their monetary policy framework. Given the success of "inflation targeting" in a wide range of economies, it seems only natural that this framework be contemplated for these economies as well. In this paper, we study how inflation targeting should be adapted to countries whose primary macroeconomic concern is the presence of sudden stops in capital inflows.

The starting point of our analysis is the observation from Caballero and Krishnamurthy (2002) that, during a sudden stop, monetary policy loses its potency. The principal constraint on output is a shortage of *external* resources. The main effect of domestic money, on the other hand, is on agents' *domestic* borrowing capacity. Thus, the knee-jerk reaction of the central bank to the outflow of capital, of raising domestic interest rates — dubbed "fear of floating" by Calvo and Reinhart (2002) — within our model is the natural consequence of a central bank that is concerned with inflation and output. Raising interest rates reduces the exchange rate depreciation, with limited effects on output beyond the impact of the external constraint. However, while fear of floating may seem optimal from this contemporaneous

perspective, it is suboptimal ex-ante .

The reason for this suboptimality is that the *anticipation* of the central bank's tight monetary policy during the sudden-stop has important effects on the private sector's incentives to insure against sudden-stop events. Insuring against these events means taking prior actions that increase the total dollar assets of the country (decrease the total dollar liabilities of the country) in the sudden-stop event. Since a contractionary monetary policy reduces the domestic scarcity value of dollars, it also lowers the returns to hoarding net dollar assets. Simply put, contracting dollar debt is less costly in an environment where the peso is expected to be supported in the event of a crisis. Thus, the anticipation of a tight monetary policy leaves the economy less insured against the sudden-stop.

In this context, expectations shape policy, not in whether inflation is anticipated or unanticipated, but in how the private sector views its rewards to insuring against sudden-stops. For incentive reasons, the optimal monetary rule is to expand during external crises, even if the expansion has a limited contemporaneous effect on output.

It should be apparent that time inconsistency is a serious issue in this context. A central bank that cannot commit will ignore the insurance aspect of monetary policy and follow a procyclical, rather than the optimal countercyclical policy. This bias is made worse by the presence of an expansionary bias a la Barro and Gordon (1983). The reason is that the central bank only sees a benefit from expanding during normal times. As a result, it lowers interest rates during these times, leading to higher inflation (as in Barro and Gordon). When the sudden-stop occurs, the central bank has even more reason to defend the exchange rate as it inherits high inflation.

In our framework, since crises are characterized by dollar shortages, there is scope for managing international reserves in order to ease these shortages. Our model provides a natural motivation for both centralized holding of reserves and holding reserves in the form of dollars. However, we show that a central bank that cannot commit will be too aggressive in injecting dollar reserves during a crisis. Moreover, this distortion interacts with the monetary policy problem. A more suboptimal monetary policy will lead to a more severe crisis, and a greater incentive for the central bank to inject reserves.

Given the time inconsistency of the central bank, what should its man-

date be? That is, how should the central bank's objectives be modified so that it internalizes the insurance dimension of the sudden-stop problem? We propose modifying inflation targeting so that the central bank follows state-contingent inflation targets, overweights nontradeable inflation in the measure of inflation that is targeted, and explicitly weighs reserves holdings in its objectives.

Since the no-commitment central bank loosens during good times and tightens during bad times, we suggest that its mandate should make the inflation target countercyclical (i.e. low during good times, and high during sudden stops). In practice, the state contingency may be implemented by making inflation targets contingent on external factors such as commodity prices, U.S. interest rates or U.S. Corporate bond spreads, and the EMBI+.

Tradables experience strong inflationary pressures during crises as the exchange rate depreciates. On other hand, the pass-through to non-tradables is more limited. Thus targeting a measure of inflation that overweights non-tradables also will reduce the central bank's incentive to raise interest rates during crises.

Finally, since the central bank injects reserves too aggressively during crises, we suggest that its objectives be modified to place weight on the stock of reserve holdings. Choosing an appropriate weight for reserves will help the central bank to internalize the effect of its exchange interventions on the private sector's insurance incentives.

Our paper is most directly related to the literature on monetary policy in economies with financial frictions (e.g., Bernanke and Blinder, 1988; Bernanke, Gertler and Gilchrist, 1999; Christiano, Roldos, and Gust, 2003; Diamond and Rajan, 2001; Gertler, Gilchrist, and Natalucci, 2001; Holmstrom and Tirole, 1998; Kiyotaki and Moore, 2001; and Lorenzoni, 2001). Unlike most of this literature, we are concerned with monetary policy in emerging markets, so we model the presence of two distinct financial constraints: one between domestic agents and one between domestic agents and foreign investors.[1]

The recent emerging markets literature has identified sudden stops of international capital flows as an important part of external crises (see, for

[1]Of the preceding literature, Diamond and Rajan is the closest to our analysis in the sense that they also model two distinct constraints: a bank solvency constraint and an aggregate liquidity constraint, in their case.

example, Calvo, 1998, and Calvo and Reinhart, 2002). Our model shares this feature. We model the sudden stop as a tightening of international financial constraints. The importance of international financial constraints for emerging markets was first identified in the sovereign debt literature (see, for example, Bulow and Rogoff, 1989).

Calvo and Reinhart (2002) offer another perspective on fear of floating. They argue that, since so much of debt in emerging market is in dollars, a central bank will recognize that the output cost of allowing the exchange rate to depreciate during a crisis is too high, and will therefore raise interest rates. In one sense, the mechanism in our model complements their explanation. An open question in the Calvo and Reinhart model is why firms take on so much dollar debt (i.e. Calvo and Reinhart take stocks of foreign debt as exogenous). We show that stabilizing the exchange rate will reduce the private sector's incentive to insure against sudden stops, and naturally leads to increasing liability dollarization (see Caballero and Krishnamurthy, 2003). On the other hand, our central bank stabilizes the exchange rate because it focuses on inflation costs, as opposed to Calvo and Reinhart's output costs. The emphasis on insurance is central to our analysis, and links us more closely to Dooley (2000), who also emphasizes insurance effects.

Our monetary policy analysis is conducted in a standard inflation targeting framework (e.g., King 1994, Svensson, 1999, or Woodford, 2002). Svensson (2000) has extended the inflation targeting framework to open economies that fit the usual small-open-economy assumption, in which countries face no international financial constraint. His analysis is most applicable to countries such as Australia or Canada, but less so to the emerging markets that are the focus of this paper.

The next two sections develop a model of monetary policy in an environment of sudden stops. Section 4 studies optimal monetary policy in this environment. Section 5 focuses on the central bank's behavior when it cannot commit to its monetary policy choices. Section 6 considers two modifications to the central bank's objectives that result in the optimal monetary policy being implemented. Section 7 adds international reserves to the model. Section 8 concludes.

## 2 A model of sudden stops

In this section we sketch a model of sudden stops. This serves as a prelude to the monetary policy analysis of the next section. The model we outline is developed more rigorously in Caballero and Krishnamurthy (2002).

Firms have assets at time $t$ of $A_t$. These are domestic assets (i.e. they generate peso revenues), so that their peso value is $A_t(i_t)$ where $i_t$ is the peso interest rate, and $A_t$ is a decreasing function.[2,3]

We assume that firms need dollars for investment. That is, they need dollars in order to import some investment goods that are inputs to production. This is justified by noting that at the margin, firms in developing countries are borrowers in international markets. We are extrapolating this demand, so that firms always have to borrow from abroad.

Moreover, we assume that firms are financially constrained so that the aggregate demand for investment goods can be written as $D(A_t, i_t^d)$. As in most models of financial constraints, the net worth of firms influences their demand. Firms sell their peso assets, worth $A_t$, along with any other peso funds they are able to borrow, in order to raise dollars for investment goods. The dollars are borrowed at interest rate of $i_t^d$, which is the price in the demand schedule. $D$ is decreasing in $i_t^d$, and increasing in $A_t$.

The supply of dollars comes from two sources. First, we assume that domestic lenders have a supply of $R_t$ dollars (small). The rest are capital inflows, $CF_t$. Thus in equilibrium,

$$D(A_t(i_t), i_t^d) = R_t + CF_t. \tag{1}$$

A supplier of dollars earns a return of

$$\frac{\mathcal{E}_t(1+i_t)}{\mathcal{E}_{t+1|t}},$$

[2]In the next section we derive a more explicit sticky price mechanism that justifies using the nominal interest rate as an argument.

[3]Note that if *domestic* liabilities are extensively dollarized, then $A_t$ also becomes a decreasing function of the exchange rate. In this case, monetary policy is less effective in influencing the peso value of domestic assets since the expansionary effect of lowering $i_t$ is offset by the depreciation such policy causes. See Caballero and Krishnamurthy (2002) for a discussion of constrained monetary regimes in an environment with sudden stops. On the other hand, dollarization of *external* liabilities can be seen as an endogenous response to the mechanism we discuss in this paper and is described in detail in Caballero and Krishnamurthy (2003).

where $\mathcal{E}_t$ is the peso/dollar exchange rate. Supplying one dollar yields $\mathcal{E}_t$ pesos today. Invested at the peso interest rate of $i_t$ and converting back into dollars tomorrow at $\mathcal{E}_{t+1|t}$ yields the above expression.

Supplying one dollar is profitable as long as this return exceeds the international interest rate $(1 + i_t^*)$. Define,

$$i_t^d \equiv \mathcal{E}_t(1 + i_t)/\mathcal{E}_{t+1|t} - 1.$$

For $i_t^d \geq i_t^*$ there is an excess return on supplying dollars to domestic firms. The spread $i_t^d - i_t^*$ is a liquidity premium.

The usual small-open-economy assumption is that the supply of dollars is perfectly elastic at the price of $i_t^d = i_t^*$. In this case, the equilibrium level of investment is simply $D(A_t, i_t^*)$. Fixing the foreign interest rate, a fall in the domestic net worth of firms (say through an increase in $i_t$) decreases investment.

The sudden stop assumption is that there are times when the country is quantity constrained in borrowing from international markets. That is,

$$CF_t \leq L_t,$$

where $L_t$ is the maximum quantity of funds that foreign investors will supply to this country. If this constraint binds, equilibrium is,

$$D(A_t, i_t^d) = R_t + L_t \quad \Rightarrow \quad i_t^d > i_t^*. \tag{2}$$

Note here that an increase in $A_t$ has no effect on investment. This is because investment is determined by the sudden stop supply of $L_t + R_t$. Instead the only effect of $A_t$ is on $i_t^d$.

Defining $e_t$ as the log exchange rate, we can rewrite the *domestic* interest parity condition as,

$$e_{t+1|t} - e_t \approx i_t - i_t^d. \tag{3}$$

When $i_t^d = i_t^*$ this is the usual interest parity condition. In that case, fixing $e_{t+1|t}$, a decrease in the peso interest rate of $i_t$ depreciates the exchange rate. In the sudden stop case, where $i_t^d > i_t^*$, the current exchange rate is depreciated relative to the future exchange rate by the size of the liquidity premium. In this case, a decrease in $i_t$ has the additional effect of causing the interest parity condition to shift upward, reinforcing the depreciation in the exchange rate.

The model we have outlined embeds two principal ideas. First, there are times when an emerging economy is financially constrained in the international market. In this instance, the supply of dollars is inelastic and the limited supply determines domestic investment and output. The second idea is that the main effect of monetary policy is on the domestic borrowing capacity of firms. In particular, decreasing interest rates during a sudden stop does not attract more capital inflows. It has a potentially very large effect on the exchange rate but limited contemporaneous effect on output. The last part of this statement follows from the right hand side of (2), which is fixed. The earlier part of the statement follows from the left hand side of the same expression and the fact that $A_t$ rises as $i_t$ falls. Thus $i^d$ must rise to ensure equilibrium; by the interest parity condition, this implies that the exchange rate depreciates not only to offset the reduction in $i_t$ but also the rise in $i_t^d$.

We denote the sudden-stop state as the $V$ regime. In the $V$ regime, $L_t + R_t$ fully determines investment. Let us imagine shifting to date $t-1$, to a point in time where private and central bank actions may influence this stock.

Suppose that at date $t-1$ the economy is not in a sudden stop. The supply of funds it faces is horizontal at $i_{t-1}^\star$ ($H$ regime). A domestic agent with some dollars at this date can either lend these funds for domestic investment or can save them in an international bond. By opting to save, the agent will be able to lend the dollar at $t$ and earn an excess return of $i_t^d - i_t^\star$. That is, the fact that $i_t^d > i_t^\star$ will induce domestic agents to "insure" against the sudden stop (raising $R_t$).

We have shown elsewhere (see Caballero and Krishnamurthy, 2001) that when domestic financial markets are underdeveloped, there is an externality – akin to a free-rider problem – whereby the market value of this benefit, $i_t^d - i_t^\star$, is less than its social value. In this circumstance, the private sector will underinsure against sudden stops. This underinsurance may take many forms: for example, borrowing too much; contracting foreign-currency denominated debt; choosing short-term debt maturities; or contracting too few credit lines (see Caballero and Krishnamurthy, 2003).

Aside from direct (and costly) regulation of capital inflows and the private sector's insurance decisions, there are two instruments at the central bank's disposal to offset the externality. First, it can increase its own holding

of foreign reserves and thereby increase $R_t$. Our model provides a natural motivation for both centralized holding of reserves and holding them in the form of international liquidity. We will return to this mechanism before concluding the paper. Second, and most important for the purpose of this paper, the central bank can commit to *expand* monetary policy during the sudden stop. Since lowering $i_t$ during the sudden stop raises $i_t^d$, this increases the private sector's incentive to self-insure. We develop this idea fully in the next sections.

## 3 Sudden stops and monetary policy

We now extend the preceding model to incorporate monetary policy and private-sector price setting. Our goal is to study optimal monetary policy in an environment of sudden stops.

At date $t-1$, we assume that the economy is in the $H$ regime. That is, the external supply of funds it faces is elastic at the interest rate of $i^*$. At date $t$, the economy either remains in the $H$ regime, or transits to the $V$ regime. The probability of remaining in $H$ is $q$, while that of entering $V$ is $1-q$. Finally, at date $t+1$, the crisis episode passes, and the economy is in the $H$ regime. We denote the nominal exchange rate at date $t+1$ as $\bar{e}$, and fix this to be independent of all events at the prior dates. At prior dates, the exchange rates are $e_t$ and $e_{t-1}$.

We are mainly interested in what happens at date $t$. At this date, aggregate demand is given by,

$$\tilde{y}_t^d = -b(r_t - i^*). \tag{4}$$

where $\tilde{y}_t^d$ is the output gap, and $i^*$ is the constant foreign interest rate (only a normalization in this equation). Foreign inflation is equal to zero.

The domestic real interest rate, $r_t$, is defined by:

$$r_t = i_t - \pi_{t+1|t} \tag{5}$$

where $i_t$ is the (peso) nominal interest rate and $\pi_{t+1|t}$ is the expectation of inflation between periods $t$ and $t+1$, conditional on information at date $t$.

On the supply side, we assume that the economy is composed of two types of price setters. Slow price-setters set their prices to grow at a constant rate

of $\bar{\pi}$ over both periods (i.e. from $t-1$ to $t$ and from $t$ to $t+1$). They choose this average growth rate to be equal to the expected rate of depreciation of the exchange rate:

$$\bar{\pi} = E_{t-1}\left[\left(\frac{e_t - e_{t-1}}{2}\right) + \left(\frac{e_{t+1} - e_t}{2}\right)\right] \tag{6}$$

Fast price-setters index their prices to the exchange rate. Putting these two groups together, and assigning positive weights of $\alpha$ and $1-\alpha$ to the slow and fast price setters, respectively, yields an inflation rate between $t$ and $t+1$ of,

$$\alpha\bar{\pi} + (1-\alpha)(e_{t+1} - e_t).$$

The expected change in the exchange rate between any two dates satisfies the *domestic* interest parity condition we derived in (3),

$$e_{t+1|t} - e_t = i_t - i_t^d. \tag{7}$$

Substituting the interest parity condition into the inflation expression yields,

$$\pi_{t+1} \equiv \pi_{t+1|t} = \alpha\bar{\pi} + (1-\alpha)(i_t - i_t^d). \tag{8}$$

We now rewrite the aggregate demand equation to account for the inflation term we have derived in equation (8). First note that,

$$r_t - i^* = \alpha(i_t - i_t^d - \bar{\pi}) + (i_t^d - i^*).$$

Substituting this into the aggregate demand expression yields,

$$\tilde{y}_t^d = -b(\alpha\tilde{i}_t + \tilde{i}_t^d), \tag{9}$$

where,

$$\tilde{i}_t \equiv i_t - i_t^d - \bar{\pi}, \qquad \tilde{i}_t^d \equiv i_t^d - i^*.$$

The aggregate demand equation, (9), is a simple parameterization of the aggregate demand in the prior section, (1). Note that it is decreasing in both the domestic (peso) real interest rate and the domestic interest rate on dollar borrowing.

Equilibrium and policy determine the domestic dollar ($i_t^d$) and peso ($i_t$) rates. Beginning with the former, in the $H$ regime domestic dollar rates

must be equal to international interest rates because the supply of dollars is perfectly elastic at $i_t^*$. Thus:

$$\tilde{i}_t^{d,H} = 0.$$

In the V regime, the sudden stop implies that $i^{d,V} > i^*$ (see (2)). We impose the sudden stop constraint directly as a constraint on output:

$$\tilde{y}_t^V = -a_y + a_d \tilde{i}_{t|t-1}^{d,V} \qquad a_y > 0. \tag{10}$$

The first term indicates that output falls below the natural level. The second term reflects the private sector's incentives to insure against the sudden stop. If the private sector anticipates a high value of $\tilde{i}_t^{d,V}$ during the sudden stop, it will be inclined to take precautionary steps. We argued earlier that in emerging markets the private value of precautioning is typically too small relative to its social value (see Caballero and Krishnamurthy, 2002, for a model showing this). Thus, in our monetary policy analysis we are concerned with ways in which the central bank can increase the incentive to take precautions.

Finally, we consider the average depreciation of the exchange rate over both periods in order to derive an expression for the $\bar{\pi}$ set by the slow price setters. First note that,

$$e_{t+1|t} - e_t = i_t - i_t^d = \tilde{i}_t^{\omega} + \bar{\pi}.$$

Next, from the interest parity condition at date $t-1$,

$$e_{t|t-1} - e_{t-1} = i_{t-1} - i^*.$$

We need to make an assumption about the central bank's behavior at date $t-1$. We make the simplest one, and assume that it sets the real domestic interest rate equal to the international interest rate (recall that foreign inflation is normalized to zero): $i_{t-1} - \bar{\pi} = i^*$. Note that this policy choice is consistent with attaining a zero output gap if the aggregate demand relation in (9) also applied at date $t-1$.

Substituting the exchange rates back into the expression for $\bar{\pi}$ from (6) gives,

$$\bar{\pi} = \frac{\bar{\pi}}{2} + \frac{E[\tilde{i}_t^{\omega}] + \bar{\pi}}{2},$$

which implies that,

$$E[\tilde{i}_t^{\omega}] = 0. \tag{11}$$

Relation (11) is central to what follows. The rate $\tilde{i}^{\omega}$ is the deviation between the average domestic real interest rate $(i_t^{\omega} - \bar{\pi})$ and the liquidity-adjusted international interest rate $(i_t^{d,\omega})$. Constraint (11) arises from rational expectations price setting by the private sector. It tells us that if the central bank chooses a low real interest rate in one of the states, in equilibrium, the real interest rate in the other state must be high.

We can rewrite the expression for $\pi_{t+1}$ more concisely using the tilde notation as,

$$\pi_{t+1} = \bar{\pi} + (1-\alpha)\tilde{i}_t^{\omega} \tag{12}$$

By symmetry with inflation at $t+1$, the inflation rate between date $t-1$ and date $t$ is

$$\pi_t = \alpha\bar{\pi} + (1-\alpha)(e_t - e_{t-1}).$$

Since, $e_t = \bar{e} - (\tilde{i}^{\omega} + \bar{\pi})$ (from interest parity condition and the assumption $e_{t+1} = \bar{e}$) and $\bar{e} - e_{t-1} = 2\bar{\pi}$ (see the definition of $\bar{\pi}$), we find that,

$$\pi_t = \bar{\pi} - (1-\alpha)\tilde{i}_t^{\omega}. \tag{13}$$

# 4 Optimal policy

Maximizing social welfare for this economy is achieved by minimizing the expected value, given information at $t-1$, of the loss function, $L$:

$$L = \lambda\tilde{y}_t^2 + \pi_t^2 + (1-\delta)\pi_{t+1}^2, \tag{14}$$

where $0 < \delta < 1$ is a discount rate.

These terms are fairly standard in the inflation targeting literature. The first term is the cost of output fluctuations around potential output, while the other terms reflect the cost of inflation. The parameter $\lambda$ determines the relative weight on output gap stabilization.

We now derive the optimal monetary policy when the central bank can commit to its choices of $(\tilde{i}_t^H, \tilde{i}_t^V)$ in advance.

The output equation in $H$ follows directly from (9), with $\tilde{i}_t^d$ set to zero:

$$\tilde{y}_t^H = -b\alpha\tilde{i}_t^H.$$

In $V$, we solve for the equilibrium $\tilde{i}_t^{d,V}$. Analogous to (2), in the $V$ regime, $i_t^{d,V}$ must be such that $y_t$ from (9) is consistent with $y_t^V$ from the external financial constraint (10). That is,

$$-b\tilde{i}_t^{d,V} - b\alpha\tilde{i}_t^V = -a_y + a_d\tilde{i}_{t|t-1}^{d,V}$$

Since $\tilde{i}_t^{d,V} = \tilde{i}_{t|t-1}^{d,V}$ under rational expectations, we see that the relation between $\tilde{i}_t^{d,V}$ and $\tilde{i}_t^V$ for *anticipated* changes in the latter is:

$$\tilde{i}_t^{d,V} = \Psi\left(a_y - b\alpha\tilde{i}_t^V\right), \qquad \Psi \equiv \frac{1}{b + a_d}. \tag{15}$$

Note that the external constraint (10) has $y_t$ increasing in $\tilde{i}_t^{d,V}$. Since $\tilde{i}_t^{d,V}$ is decreasing in $\tilde{i}_t^V$, this means that lowering $\tilde{i}_t^V$ has a beneficial effect on output in $V$. The effect is through an "insurance" channel. By anticipating a lower $\tilde{i}_t^V$ during the sudden stop, the expectation of $\tilde{i}_t^{d,V}$ rises. That is, the return to insuring against the sudden stop increases, and this relaxes the aggregate financial constraint. On the other hand, the usual aggregate demand effect of lowering interest rates – the contemporaneous effect of $\tilde{i}_t^V$ on $y$ – is absent in the $V$ regime. Ex-post, since $\tilde{i}_t^V$ is fixed at date $t$, the positive effect on aggregate demand of a reduction in $\tilde{i}_t^V$ is fully offset by the negative effect of the corresponding rise in $\tilde{i}_t^{d,V}$.

When state-contingent monetary policy is fully anticipated, output in $V$ is,

$$\tilde{y}_t^V = -\Psi b(a_y + \alpha a_d\tilde{i}_t^V).$$

We assume throughout that $\tilde{y}_t^V < 0$, so that increasing $\tilde{y}_t^V$ lowers the objective in (14).[4]

The objective for the central bank is,

$$\min_{(\tilde{i}_t^H, \tilde{i}_t^V, \tilde{\pi})} qL^H + (1-q)L^V$$

where,

$$L^V = \lambda(b\Psi)^2(a_y + \alpha a_d\tilde{i}_t^V)^2 + (\bar{\pi} - (1-\alpha)\tilde{i}_t^V)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^V)^2$$

[4]This means assuming that $\frac{1}{\alpha}\frac{a_y}{a_d} > -\tilde{i}_t^V$. Although, $\tilde{i}_t^V$ is an endogenous variable, it is possible to show that the assumption can always be met by choosing $a_y$ large enough.

and,

$$L^H = \lambda(b\alpha\tilde{i}_t^H)^2 + (\bar{\pi} - (1-\alpha)\tilde{i}_t^H)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^H)^2$$

subject to the rational expectations constraint that,

$$E[\tilde{i}_t^\omega] = 0.$$

Let us start with the first order condition with respect to $\bar{\pi}$, which is straightforward:

$$\begin{aligned}
\frac{\partial L}{\partial \bar{\pi}} &= 2(1-q)(\bar{\pi} - (1-\alpha)\tilde{i}_t^V) + 2(1-\delta)(1-q)(\bar{\pi} + (1-\alpha)\tilde{i}_t^V) \\
&\quad +2q(\bar{\pi} - (1-\alpha)\tilde{i}_t^H) + 2(1-\delta)q(\bar{\pi} + (1-\alpha)\tilde{i}_t^H) \\
&= 2\bar{\pi} - 2(1-\alpha)E[\tilde{i}_t^\omega] + 2(1-\delta)(\bar{\pi} - (1-\alpha)E[\tilde{i}_t^\omega]) \\
&= 2(2-\delta)\bar{\pi} = 0 \qquad \Rightarrow \qquad \bar{\pi}^c = 0,
\end{aligned}$$

where the superscript $c$ stands for the commitment solution. Thus, in the full commitment case, the central bank chooses policy so as to achieve a zero average rate of inflation. Since all price setters take into account average inflation, there is no benefit, only costs, for the central bank to choose a positive average inflation.

This does not mean that monetary policy is impotent. If we compute the marginal benefit of increasing $\tilde{i}_t^V$, at neutral interest rates and $\bar{\pi}^c$, we find

$$\frac{\partial L}{\partial \tilde{i}_t^V}|_{\tilde{i}_t^H = \tilde{i}_t^V = \bar{\pi} = 0} = 2(1-q)\lambda\alpha a_d a_y (b\Psi)^2 > 0$$

which implies that the central bank will choose $\tilde{i}_t^V < 0$ (since we are minimizing the objective).

The exact solution is,

$$\tilde{i}_t^V = -a_y \frac{q\lambda\alpha a_d (b\Psi)^2}{\lambda(b\alpha)^2 \left(q(\Psi a_d)^2 + 1 - q\right) + (2-\delta)(1-\alpha)^2}. \tag{16}$$

The central bank sets $i_t^V$ below $i_t^{d,V}$ in order to increase the private sector's incentives to insure against the sudden stop. The cost of this policy is that the exchange rate depreciates in the $V$ regime. To offset the effect of this policy on average inflation, the central bank chooses $\tilde{i}_t^H > 0$ (see (11)), so that policy is tighter in the $H$ regime, and output is lower.

Note that as a result of its attempt to increase precautioning against the $V$ regime and hence increase $\tilde{y}^V$, the central bank tolerates some instability in inflation and exchange rates.

# 5 The central bank without commitment

Let us now study a central bank that cannot commit to the interest rate choices of date $t$, prior to this date. Two biases arise from the lack of commitment. First, if the central bank's preferences are as stated in (14) it will choose interest rates to completely stabilize the exchange rate ("fear of floating"). Second, if the central bank's preferences are distorted so as to always prefer to increase output, as in Barro and Gordon (1983), then the fear of floating problem is made worse. The central bank loosens in the $H$ state, and tightens in the $V$ state, while inducing a positive average rate of inflation. This is exactly the opposite of the policy dictated in the commitment solution.

## 5.1 Fear of floating

Suppose that the central bank chooses interest rates in each state ($H$ or $V$) to minimize the loss function in (14). Then in $H$, it solves,

$$\min_{\tilde{i}_t^H} L^H = \lambda(b\alpha\tilde{i}_t^H)^2 + (\bar{\pi} - (1-\alpha)\tilde{i}_t^H)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^H)^2$$

while in $V$, it solves,

$$\min_{\tilde{i}_t^V} L^V = (\bar{\pi} - (1-\alpha)\tilde{i}_t^V)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^V)^2.$$

Compared to the loss function in $V$ of the previous section, the main change is that there is no output term. This follows from our assumption in (10), that there is no aggregate demand channel whereby lowering interest rates increases output. The loss function in $H$ is the same as in the previous section.

It is easy to verify that the solution to these two problems (that is consistent with the rational expectations requirement that $\mathrm{E}[\tilde{i}_t^\omega] = 0$) is to set $\tilde{i}_t^H = \tilde{i}_t^V = 0$, with $\bar{\pi} = 0$. Note that at $\bar{\pi} = 0$, inflation and the exchange

rate are fully stabilized by choosing $\tilde{i}_t^H = \tilde{i}_t^V = 0$. In addition, the output gap in $H$ is equal to zero.

While the policy stabilizes both inflation and the exchange rate, the cost is that output is drops too much in the sudden-stop state, $V$. The central bank essentially ignores the insurance channel of monetary policy, and focuses purely on maintaining a stable exchange rate.

### 5.2 Exacerbating the problem: Barro-Gordon

We now modify the central bank's objective function to introduce an expansionary bias a la Barro-Gordon (1983):

$$L = -\lambda \tilde{y}_t + \pi_t^2 + (1-\delta)\pi_{t+1}^2. \tag{17}$$

The $\tilde{y}_t$ term now reflects the central bank's preference to always raise output. We drop the squared-output term since it does not change our message.

The choice problem in $H$ is,

$$\min_{\tilde{i}_t^H} L^H = \lambda b \alpha \tilde{i}_t^H + (\bar{\pi} - (1-\alpha)\tilde{i}_t^H)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^H)^2.$$

This gives the first order condition:

$$\tilde{i}_t^H = \frac{\delta}{2-\delta}\frac{1}{1-\alpha}\left(\bar{\pi} - \frac{\lambda b \alpha}{2(1-\alpha)\delta}\right). \tag{18}$$

Note that a larger value of $\lambda$ (greater preference for increasing output) leads to a lower interest rate choice. A higher value of $\bar{\pi}$ offsets this tendency.

The choice problem in $V$ remains the same as in the fear of floating case since output, as of date $t$, is fixed:

$$\min_{\tilde{i}_t^V} L^V = (\bar{\pi} - (1-\alpha)\tilde{i}_t^V)^2 + (1-\delta)(\bar{\pi} + (1-\alpha)\tilde{i}_t^V)^2.$$

The first order condition is,

$$\tilde{i}_t^V = \frac{\delta}{2-\delta}\frac{\bar{\pi}}{1-\alpha}. \tag{19}$$

Since in equilibrium, we must have that $\mathrm{E}[\tilde{i}_t^\omega] = 0$, it follows from (18) and (19) that,

$$\bar{\pi} = \lambda \frac{qb\alpha}{2(1-\alpha)\delta} > 0.$$

Replacing this expression back into (18) and (19), we find that $\tilde{i}_t^H < 0$ and $\tilde{i}_t^V > 0$:

$$\tilde{i}_t^H = -(1-q)\lambda \frac{qb\alpha}{2(1-\alpha)^2\delta} < 0,$$

$$\tilde{i}_t^V = \lambda \frac{qb\alpha}{2(1-\alpha)^2\delta} > 0.$$

The central bank preference for increasing output has a perverse effect in our model. Since lowering interest rates in $H$ increases output, the central bank sets $\tilde{i}^H < 0$. As in Barro-Gordon, the anticipation of the low interest rate in $H$ raises the private sector's inflation expectations, and leads to $\bar{\pi} > 0$. In $V$, the central bank sees no output benefit to changing interest rates since output is predetermined by the sudden stop supply. However, since the average rate of inflation is now positive, the central bank is faced with an exchange rate that depreciates at date $t$. To counter this, the central bank raises the interest rate in $V$. In equilibrium, this leads to a lower $\tilde{i}_t^{d,V}$, and an even tighter sudden stop supply. The crisis is thereby exacerbated.

# 6 Implementing optimal policy through inflation targets

Given the time inconsistency of the central bank, what should its mandate be? That is, how should the central bank's objectives be modified so that it internalizes the insurance dimension of the sudden stop problem? In this section we highlight two possibilities. First, inflation targets can be made state dependent: stringent (low) in $H$ and loose (high) in $V$. Second, the central bank's mandate can overweight the inflation of non-tradables in the measure of inflation that it targets. Since output contracts in the $V$ regime, there is deflation in non-tradables. The inflation-targeting central bank offsets this by lowering interest rates and causing the exchange rate to depreciate (leading to inflation in tradables). This incentive increases by placing a larger weight on non-tradables.

## 6.1 State contingent inflation targets

We continue with the linear-output specification but modify the central bank's objective function to introduce a state-contingent inflation penalty

term of $\kappa^\omega$, for $\omega \in \{H, V\}$:

$$L = -\lambda \tilde{y}_t + (\pi_t - \kappa^\omega)^2 + (1-\delta)(\pi_{t+1} - \kappa^\omega)^2. \tag{20}$$

A positive $\kappa$ means that inflation is less costly for the central bank, while a negative $\kappa$ penalizes inflation further.

The choice problem in $H$ is,

$$\min_{\tilde{i}_t^H} L^H = \lambda b \alpha \tilde{i}_t^H + (\bar{\pi} - \kappa^H - (1-\alpha)\tilde{i}_t^H)^2 + (1-\delta)(\bar{\pi} - \kappa^H + (1-\alpha)\tilde{i}_t^H)^2.$$

This gives the first order condition:

$$\tilde{i}_t^H = \frac{\delta}{2-\delta}\frac{1}{1-\alpha}\left(\bar{\pi} - \kappa^H - \frac{\lambda b \alpha}{(1-\alpha)\delta}\right).$$

Note that, everything else constant, a larger value of $\kappa^H$ leads to a lower interest rate in $H$.

The choice problem in $V$ is:

$$\min_{\tilde{i}_t^V} L^V = (\bar{\pi} - \kappa^V - (1-\alpha)\tilde{i}_t^V)^2 + (1-\delta)(\bar{\pi} - \kappa^V + (1-\alpha)\tilde{i}_t^V)^2.$$

The first order condition is now,

$$\tilde{i}_t^V = \frac{\delta}{2-\delta}\frac{\bar{\pi} - \kappa^V}{1-\alpha}.$$

As before, since in equilibrium we must have that $\mathrm{E}[\tilde{i}_t^\omega] = 0$, we obtain:

$$\bar{\pi} = \lambda \frac{qb\alpha}{2(1-\alpha)\delta} + (1-q)\kappa^V + q\kappa^H.$$

We note that in the commitment solution $\bar{\pi}$ is equal to zero. Imposing $\bar{\pi} = 0$ yields a constraint across $\kappa^\omega$:

$$\kappa^H = -\frac{\lambda b \alpha}{2(1-\alpha)\delta} - \frac{1-q}{q}\kappa^V.$$

If there is a strong Barro-Gordon inflation bias (high $\lambda$), then $\kappa^H$ can be made low in order to offset this bias. Similarly, to the extent that the central bank has a loose inflation target in $V$ (if $\kappa^V$ is high), $\kappa^H$ can be set low so the net result is a $\bar{\pi}$ of zero.

Substituting this $\kappa$ expression back into the first order conditions for interest rate choices allows us to solve for the optimal interest rate choices:

$$\tilde{i}_t^H = \frac{\delta}{2-\delta}\frac{1}{1-\alpha}\frac{1-q}{q}\kappa^V$$

and

$$\tilde{i}_t^V = -\frac{\delta}{2-\delta}\frac{1}{1-\alpha}\kappa^V.$$

By choosing $\kappa^V > 0$ (and hence $\kappa^H < 0$), the central bank will follow a state contingent policy as dictated in the social optimum, with $\tilde{i}_t^H > 0$ and $\tilde{i}_t^V < 0$. In equilibrium, this leads to a higher $\tilde{i}_t^{d,V}$, and a looser sudden stop supply. The crisis is thereby lessened.

Before concluding this section, note that both the state-contingent inflation target and the nontradeable-inflation overweight solutions act through the inflation terms of the central bank objective. If we were to introduce a contemporaneous output effect of a change in $\tilde{i}^V$, these recommendations would remain but there would be an additional channel open: We could now also achieve the desirable effect by raising the weight of output in the central bank's objective during $V$-regimes.

### 6.2 Non-tradable inflation target

Let us now introduce an infinitesimal (in the sense that it does not feedback into aggregate demand) non-tradable good, whose inflation is determined by a simple Phillips curve:

$$\pi_t^N = \bar{\pi} + \tilde{y}_t.$$

We modify the measure of inflation that the central bank targets to be a weighted average of $\pi_t^N$ and the tradable inflation of $\pi_t$ that we have been using so far. The central bank's objective function is,

$$L = -\lambda\tilde{y}_t + (\beta\pi_t^N + (1-\beta)\pi_t - \kappa^\omega)^2 + (1-\delta)(\beta\pi_{t+1}^N + (1-\beta)\pi_{t+1} - \kappa^\omega)^2. \quad (21)$$

$\beta$ is the weight on non-tradable inflation. We normalize the $t+1$ (non-crisis) inflation rate on non-tradables to be zero. Finally we set $\kappa^V = 0$ (leaving $\kappa^H \neq 0$).

The choice problem in $V$ is:

$$\min_{\tilde{i}_t^V} L^V = (\bar{\pi} + \beta\tilde{y}_t^V - (1-\beta)(1-\alpha)\tilde{i}_t^V)^2 + (1-\delta)(1-\beta)^2(\bar{\pi} + (1-\alpha)\tilde{i}_t^V)^2.$$

The first order condition is,

$$\tilde{i}_t^V = \frac{\bar{\pi}(1-(1-\beta)(1-\delta)) + \beta\tilde{y}_t^V}{(1-\alpha)(1-\beta)(2-\delta)}.$$

The choice problem in $H$ is,

$$\min_{\tilde{i}_t^H} L^H = \lambda b\alpha\tilde{i}_t^H + (\bar{\pi} - \kappa^H - \beta b\alpha\tilde{i}_t^H - (1-\alpha)\tilde{i}_t^H)^2 + (1-\delta)(1-\beta)^2(\bar{\pi} - \frac{\kappa^H}{1-\beta} + (1-\alpha)\tilde{i}_t^H)^2.$$

This gives a solution for $\tilde{i}_t^H$ that is linearly increasing in $\bar{\pi}$, decreasing in $\lambda$, and decreasing in $\kappa^H$.

As in the previous section we can always choose $\kappa^H$ so that $\bar{\pi} = 0$. That is, when we impose the equilibrium condition that $E[\tilde{i}_t^\omega] = 0$, we arrive at a relation for $\bar{\pi}$ in terms of $\kappa^H$. We simply choose $\kappa^H$ so that $\bar{\pi}$ equals zero.

Given this $\kappa^H$, $\tilde{i}_t^V$ is proportional to $\beta\tilde{y}_t^V$. Since $\tilde{y}_t^V < 0$, we can implement $\tilde{i}_t^V < 0$ by choosing $\beta > 0$. Since $E[\tilde{i}_t^\omega] = 0$, this means that $\tilde{i}_t^H > 0$, which is achieved by setting $\kappa^H < 0$.

By increasing the weight on nontradables in the measure of inflation that the central bank targets, the central bank follows a state contingent policy as dictated in the social optimum. Again, in equilibrium, this leads to a higher $\tilde{i}_t^{d,V}$, and a looser sudden-stop supply.

## 7 Reserves management

Since crises are characterized by dollar shortages (see equation (2)), there is scope in the model for managing international reserves in order to ease these shortages. Our model provides a natural motivation for both centralized holding of reserves and for holding them in the form of dollars.

We assume that the central bank has a small amount of international reserves at date $t$. These reserves can be injected at date $t$, or saved for use beyond date $t+1$, when they yield $\gamma > 0$ utils per unit of reserves. The latter represents the opportunity cost of using the reserves early, and should be interpreted more broadly as the value of precautioning.

We contrast how the results of section 4 and section 5.1 change upon the introduction of international reserves. The loss function in both cases is modified to:

$$L = \lambda\tilde{y}_t^2 + \pi_t^2 + (1-\delta)\pi_{t+1}^2 + \gamma R_t, \tag{22}$$

with $R_t$ the amount of reserves injected.

Recall that in section 4, we solve for the interest rate choices that the central bank commits to in minimizing the loss function. While, in section 5.1, we solve for the sequentially optimal interest rate choices given this loss function.

There is no value in injecting reserves in $H$. Since there is no dollar shortage, the action has no effect on either prices or output. Reserves will be hoarded because failing to do so has an opportunity cost $\gamma$. In the $V$ regime, the action increases dollar supply and relaxes the vertical constraint: (10) to:

$$\tilde{y}_t^V = R_t^V - a_y + a_d \tilde{i}_{t|t-1}^{d,V}. \tag{23}$$

One can see from this expression, that $R_t^V$ enters exactly as $-a_y$ in all the expressions. In particular,

$$\tilde{y}_t^V = \Psi b(R_t^V - a_y - \alpha a_d \tilde{i}_t^V). \tag{24}$$

As we discussed earlier, the optimal policy considers the dependence of $\tilde{y}_t^V$ on $\tilde{i}_t^{d,V}$ (which enters through expectations), while the no-commitment case does not.

The introduction of international reserves management considerations does not change any of the main qualitative conclusions with respect to monetary policy in either the commitment or no-commitment case of sections 4 and 5.1, respectively. In particular, it is still the case that $\bar{\pi} = 0$ in both cases; that $\tilde{i}^H = \tilde{i}^V = 0$ in the no-commitment case; and that $\tilde{i}^H > 0$ and $\tilde{i}^V < 0$ in the commitment case.[5]

However, reserve injections are a substitute for (countercyclical) monetary policy. To see this, note that in the commitment solution for $\tilde{i}_t^V$ in equation (16), $\tilde{i}_t^V$ is decreasing in $a_y$. Since $R_t^V$ enters as $-a_y$ in all expressions, the reserve injection increases the optimal $\tilde{i}_t^V$.

The most interesting new result comes from the first order condition with respect to $R_t^V$. From equations (22) and (24), the solution for $R_t^V$ in the commitment case is:

$$R_t^{V,c} = -\frac{\gamma}{2\lambda(b\Psi)^2} + a_y + \alpha a_d \tilde{i}_t^V. \tag{25}$$

[5]These statements assume that $R_t < a_y$, so that there is insufficient international reserves to eliminate the sudden stop shock.

From equations (22) and (23), the solution for $R_t^V$ in the no-commitment case is:

$$R_t^{V,nc} = -\frac{\gamma}{2\lambda b\Psi} + a_y + \alpha a_d \tilde{i}_t^V . \tag{26}$$

Note that $b\Psi = \frac{b}{b+a_d} < 1$, so the first term is more negative in the commitment case. Also, since for any equilibrium level of $R_t^V$, $\tilde{i}_t^{V,c} < \tilde{i}_t^{V,nc}$, we have that $R_t^{V,nc} > R_t^{V,c}$. That is, the central bank with no commitment not only will use too little monetary policy, but it also will inject reserves too aggressively.

There are two factors behind this result. First, injecting reserves both increases output and decreases $\tilde{i}_t^{d,V}$. Ex-post, the central bank considers the output benefit, but ignores the effect on $\tilde{i}_t^{d,V}$. Ex-ante, the central bank accounts for the second effect: the lower $\tilde{i}_t^{d,V}$ decreases the private sector's incentives to insure against the sudden stop shock. The latter effect makes the commitment-central-bank inject less reserves than the no-commitment one.

The second factor has to do with the time inconsistency of monetary policy. In the no-commitment solution, the central bank has to offset a larger crisis caused by the inadequate monetary policy. As a result, it over-injects its reserves.

The latter factor is remedied indirectly by solving the monetary policy time inconsistency problem as we have discussed. The former factor, on the other hand, requires further modification to the central bank's mandate so that it increases the value it assigns to hoarding reserves during the $V$-regime.

## 8 Final remarks

We have analyzed monetary policy in an environment of sudden stops. Sudden stops are times when a country is financially constrained in the international financial market. In this context, lowering or raising domestic interest rates has only small effects on the tightness of this financial constraint, but does have significant effects on the domestic borrowing capacity of agents. Moreover, the anticipation of such actions are important in determining precautionary actions that agents take against sudden stops.

From this viewpoint, we have derived positive and normative results for

monetary policy and reserves management. We have highlighted a new time inconsistency problem and its interaction with the conventional stabilization bias. Finally, we have suggested how an inflation targeting framework can restore incentives, so that central banks behave optimally.

Our model is clearly very stylized. In particular, our assumption that the country faces a vertical supply of funds during sudden stops is extreme. But it is important to realize that our main conclusions do not depend on this extreme. We could consider a more general model in which the supply of funds was not completely inelastic in the $V$ regime. In this case, the $V$ regime would have both an aggregate demand channel and the insurance channel we have highlighted (i.e. lowering $\tilde{i}_t^V$ leads to a contemporaneous increase in $\tilde{y}_t^V$). Importantly, relative to the $H$-regime, the output-inflation tradeoff will still turn steeper (although not vertical) during the $V$-regime and hence the central bank will be prone to favor inflation over output targets more than in the $H$ regime. Moreover, as long as the insurance channel is present, this reaction will remain suboptimal.

Insurance against sudden stops affects many policy decisions in emerging markets, from reserve management to liquidity ratio requirements. It seems only natural that optimal monetary policy be analyzed in the same light, as in this paper. Moreover, it is important to understand the interaction of monetary policy with other insurance policies (as we have with reserve policies). We hope that our framework provides a starting point for such an integrated approach.

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